

# Images of the Antiferromagnetic Structure of a NiO(100) Surface by Means of X-Ray Magnetic Linear Dichroism Spectro-Microscopy

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## INTRODUCTION

Atomically engineered magnetic thin film structures are used in a great variety of devices, such as magnetic data storage media in computer hard drives, magnetic sensors or in future applications such as non-volatile random access memory (RAM). Antiferromagnetic layers are an important and scientifically challenging component in these devices. The antiferromagnet magnetically pins or “exchange biases” the magnetization of a ferromagnetic layer to serve as a magnetic reference. Due to its compensated magnetic structure antiferromagnets are insensitive to applied magnetic fields. On the other hand, the lack of a macroscopic moment impedes the investigation of the magnetic properties of antiferromagnetic thin films, explaining the ongoing controversies on the origin of exchange biasing. Photoelectron emission microscopy (PEEM) is capable to determine the surface magnetic structure of antiferromagnets which is demonstrated for thin NiO(100) films. Imaging of the magnetic structure at the surface of the antiferromagnetic layer is an important and necessary step towards an understanding of exchange coupling effects across the ferromagnet – antiferromagnet interface, a step which could also help the magnetic-storage industry to further optimize their products.

The photoelectron emission microscope PEEM2 located at beam line 7.3.1.1 of the Advanced Light Source (ALS), offers high spatial resolution ( $< 50$  nm) in conjunction with magnetic contrast to investigate ferro- and antiferromagnetic thin film structures [1]. Photoelectrons emitted from the sample, which is illuminated by intense monochromatic x-rays, are imaged by an electron optics onto a phosphor screen. Magnetic contrast arises from the dependence of the absorption coefficient and thereby the intensity of electron emission on the relative orientation of the x-ray polarization and the orientation of the magnetic axis. This effect is called x-ray magnetic dichroism (XMD). X-ray magnetic *linear* dichroism (XMLD) contrast, using linearly polarized x-rays, has been applied in the investigation of thin NiO(100) films, epitaxially grown on a MgO(100) single crystal substrate [2]. NiO is of technological importance as an antiferromagnetic material in exchange biasing applications and can be called a benchmark material.

## RESULTS

Figure 1 shows an antiferromagnetic image with a  $30\text{ }\mu\text{m}$  field of view for a  $80\text{ nm}$  thick NiO(100) film. The image exhibits straight bright lines or stripes with typical widths between  $400\text{ nm}$  and  $2000\text{ nm}$  on a darker background. Such features are observed at other locations on the same sample and on other samples with different NiO thicknesses in the  $10\text{--}80\text{ nm}$  range. The lines are several  $100\text{ }\mu\text{m}$  long and the fact that similar structures are also observed by AFM indicates that the lines in our image are correlated with the structure of the surface. However, the contrast in Figure 1 is of antiferromagnetic and not of topographic nature. This is demonstrated

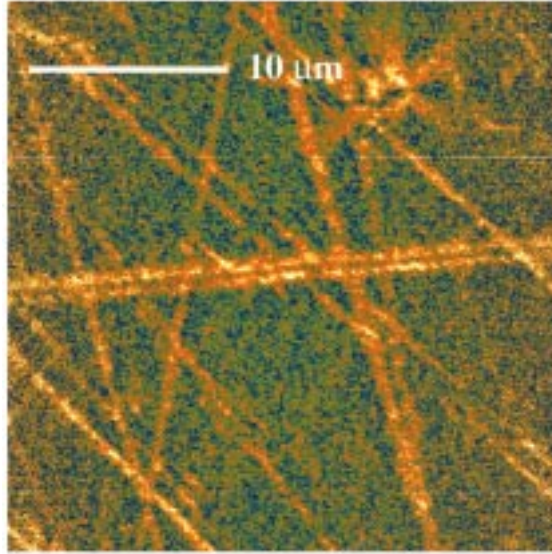


Figure 1: XMLD antiferromagnetic image of a 80 nm thick NiO(100) film on MgO(100)

by the temperature dependence of the image shown in Figure 2. Here we show three images recorded at 290, 425 and 520 K, respectively. Clearly, the contrast disappears gradually as the Néel temperature of the film is approached. The temperature dependence is reversible and the XMLD contrast is fully restored upon returning to room temperature. This indicates that the line-like antiferromagnetic regions are pinned by the surface structure of the film. A careful image analysis shows that the contrast in the XMLD images arises from a reduced average out-of-plane magnetic moment in the brighter lines.

We can quantify the temperature dependent antiferromagnetic contrast in the XMLD images by direct comparison of the intensity of the stripes and the intensity of the darker areas. In Figure 3 we show a temperature dependent plot of the line contrast from Figure 2 defined as the difference of the line intensity (area) and the background intensity, normalized to the background intensity. From the fit we estimate the Néel temperature inside the stripes to 455 K which is significantly reduced compared to bulk NiO (520 K) and to the ordering temperature that we observe outside the stripes. This is attributed to a finite size effect associated with the reduced dimension of the lines. The present study demonstrates the use of XMLD spectro-microscopy for obtaining detailed mesoscopic information on the antiferromagnetic structure of epitaxial thin films and

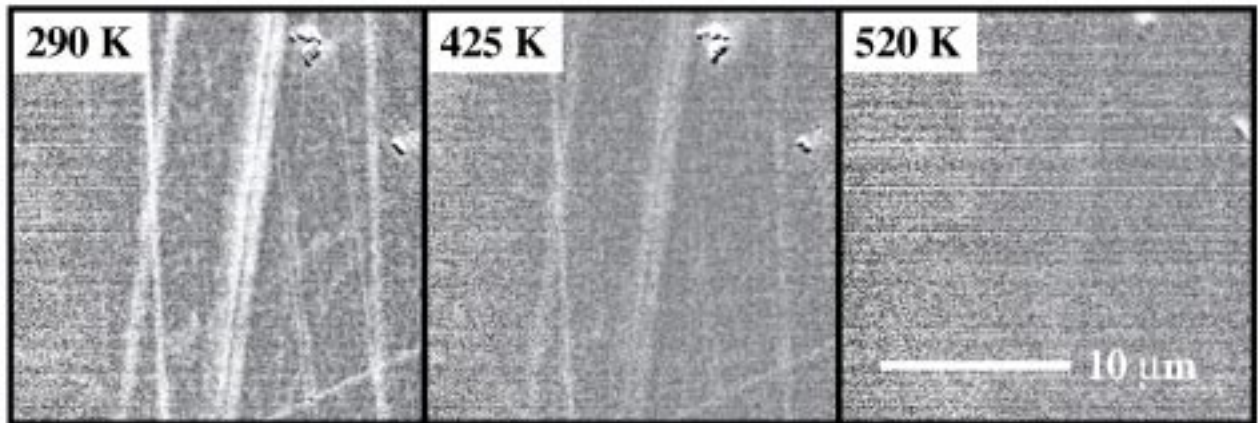


Figure 2: Temperature dependence of the antiferromagnetic XMLD contrast.

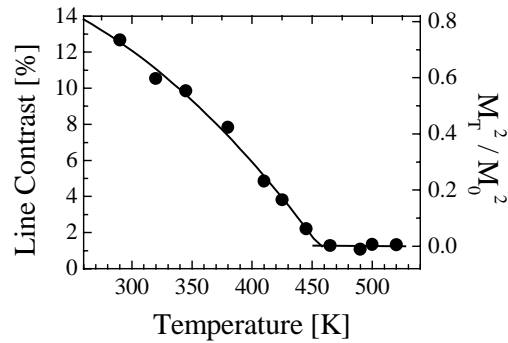


Figure 3: Temperature dependence of line contrast, right axis shows square of magnetic moment

their surfaces. More generally, it is clear that the technique can be extended to the study of polycrystalline surfaces and to interfaces between thin films.

## REFERENCES

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2. J. Stöhr et al., "Images of the antiferromagnetic structure of a NiO(100) surface..." Phys. Rev. Lett. 83, 1862 (1999)

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